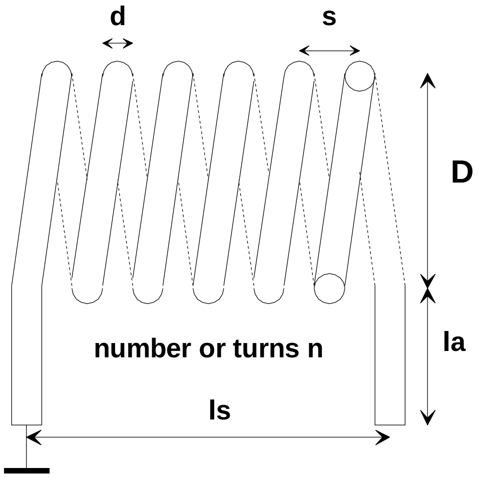
Intrinsic Capacity C0 of a Single Layer Solenoid and it's Influence on the Q-Factor



$\alpha = \frac{ls}{D}$

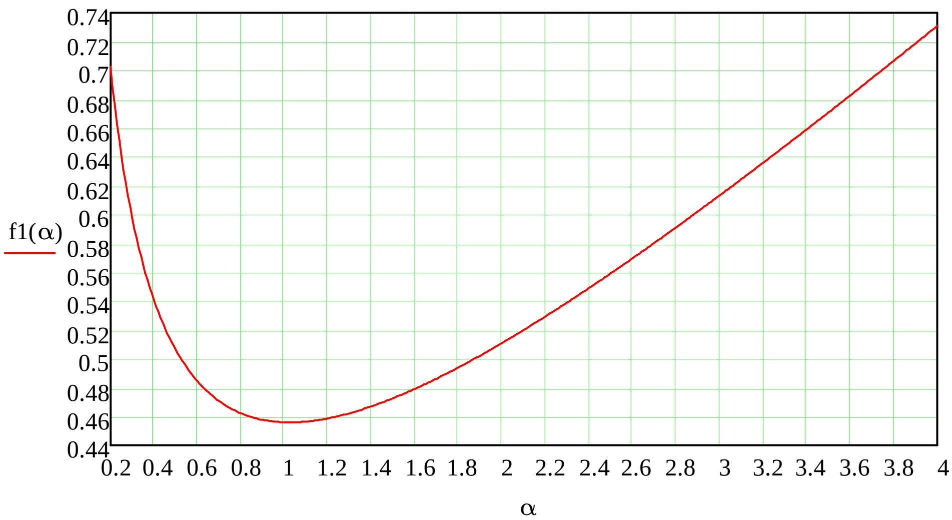
f = measuring (working) frequency

f0 = self resonance frequency (SRF)

Calculation of the intrinsic capacity of a coil using the tables given by Medhurst

one end of the coil having earth potentional

we scan: $\alpha := 0.2, 0.21 .. 4$ $\quad f1(\alpha) := 0.026 + 0.14 \cdot \alpha + \frac{0.29}{\sqrt{\alpha}}$



example: $D := 8.37 \quad ls := 3.9$ [cm] $\quad \alpha := \frac{ls}{D} \quad C01 := D \cdot \left(0.026 + 0.14 \cdot \alpha + \frac{0.29}{\sqrt{\alpha}}\right) = 4.32$ [pF]

What we can see:
- the capacity is independent of the wire diameter.
- the capacity is independent of the number of turns.
- the smallest capacity occures at α = 1
- for volume-optimized coils there C0 is one half of a picofarad per cm diameter of the coil.

Capacity of the hot connecting wire

$d := 2$ [mm] $\quad la := 13.2$ [cm] $\quad C02 := la \cdot 0.0855 \cdot d^{0.29} = 1.38$ [pF]

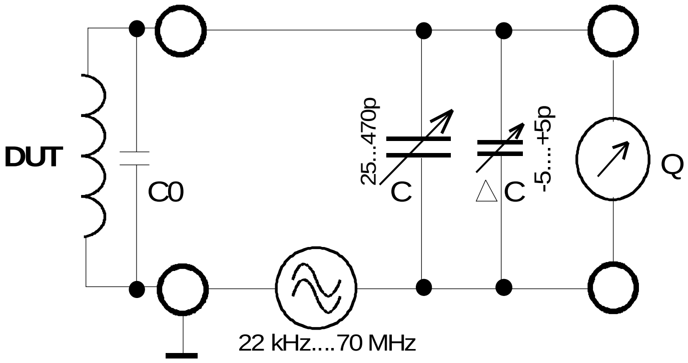
total capacitve load $\quad C0 := C01 + C02 = 5.70$ [pF]

With C0 we can correct Q and L:

$$Qcorr = Q \cdot \left(1 + \frac{C0}{C}\right) = Q \cdot \left[1 + \left(\frac{f}{f0}\right)^2\right] \quad Lcorr = L \cdot \left(\frac{1}{1 + \frac{C0}{C}}\right) = L \cdot \left[\frac{1}{1 + \left(\frac{f}{f0}\right)^2}\right]$$

Measuring of the capacitive load of a single layer solenoid with HP 4342A

Measuring principle of the HP 4342A



f0 = self resonance frequency (SRF)

Principle : At resonance the parallel voltage across C is Q-times higher than the series voltage of the generator. This is true if the source impedance is zero and the load impedance is infinite. Next condition is: C0 must be zero. While the impedance conditions are fulfilled by Hewlett Packard, the C0 must be considered.

The current coming up through L is divided up into C0 and C+ΔC. The current through C0 does not contribute to the Voltage Q. So the indicated value is too small. Reading C and f we can calculate L. The existance of C0 lowers the reading of C. So the calculation of L gives a value which is too high.

In order to work out the proper L and Q of the coil we need either C0 or the SRF (Self Resonance Frequency)

Method 1:
- connect DUT (Device under Test) on the left side
- set C to 20p. (C=25p, ΔC= - 5p) this is C1
- set frequency to resonance
- lower frequency by one step. $1/\sqrt{10}$
- vary C to resonance, read C2
- calculate

$$C0 = \frac{C2 - 10 \cdot C1}{10 - 1} \qquad C0 = \frac{C2 - 200}{9} \quad \text{[pF]}$$

Method 2:
- connect DUT (Device under Test) on the left side
- set C to 20p. (25 - 5) read C1
- vary frequency to resonance, read f1
- set C to 470p (470 + 0) read C2
- vary frequency for resonance, read f2
- calculate

$$C0 = \frac{C2 - \left(\frac{f1}{f2}\right)^2 \cdot C1}{\left(\frac{f1}{f2}\right)^2 - 1}$$

Methode 3: Here we have a Methode to find the SRF directly. According to the manual ist is the most accurate method possible with this type of measuring gear.

- connect any auxillary coil of ca. 0.1...0.3 µH or the reference coil Nr. 19 resp.18 to the left side of the gear.
- resonate it with C (ΔC = 0) at the expected SFR of the DUT.
- connect the DUT to the right side of the gear.
- search the new resonance by varying ΔC
- if you have to increase ΔC, increase the frequency. If you have to decrease ΔC, decrease the frequency.
- Repeat this procedure until the resonance frequency is no more affected by the DUT. This is the SFR because the impedance is real and does not influence the the resonance of the aux. coil. Tedious work which takes some time.

Method 4: Very often we have to deal with an inductor having a SFR higher than 70 MHz. That means Method 3 is useless. Let's find a Method nearly as good for frequencies above 70 MHz.

- measure the inductance ot the DUT at the lowest possible frequency. That saves us to correct the value for C0.
- connect the auxiliary coil of ca.0.1 µH to the left side as in method 3.
- set the generator to 70 MHz.
- hunt for resonance with C (ΔC = 0). Read C.
- connect DUT to the right side.
- seek resonance with ΔC, ev. C. Read the change. ΔC
- calculate

$$C0 = \frac{5.169}{L} - \Delta C \quad [\mu H, pF]$$

Here are the corrections again

$$Qcorr = Q\cdot\left(1 + \frac{C0}{C}\right) = Q\cdot\left[1 + \left(\frac{f}{f0}\right)^2\right] \qquad Lcorr = L\cdot\left(\frac{1}{1 + \frac{C0}{C}}\right) = L\cdot\left[\frac{1}{1 + \left(\frac{f}{f0}\right)^2}\right]$$

The first selfresonance

$$f0 = \frac{1}{2\cdot\pi\cdot\sqrt{Lcorr\cdot C0}}$$

Effective L and Q at a frequency f < f0

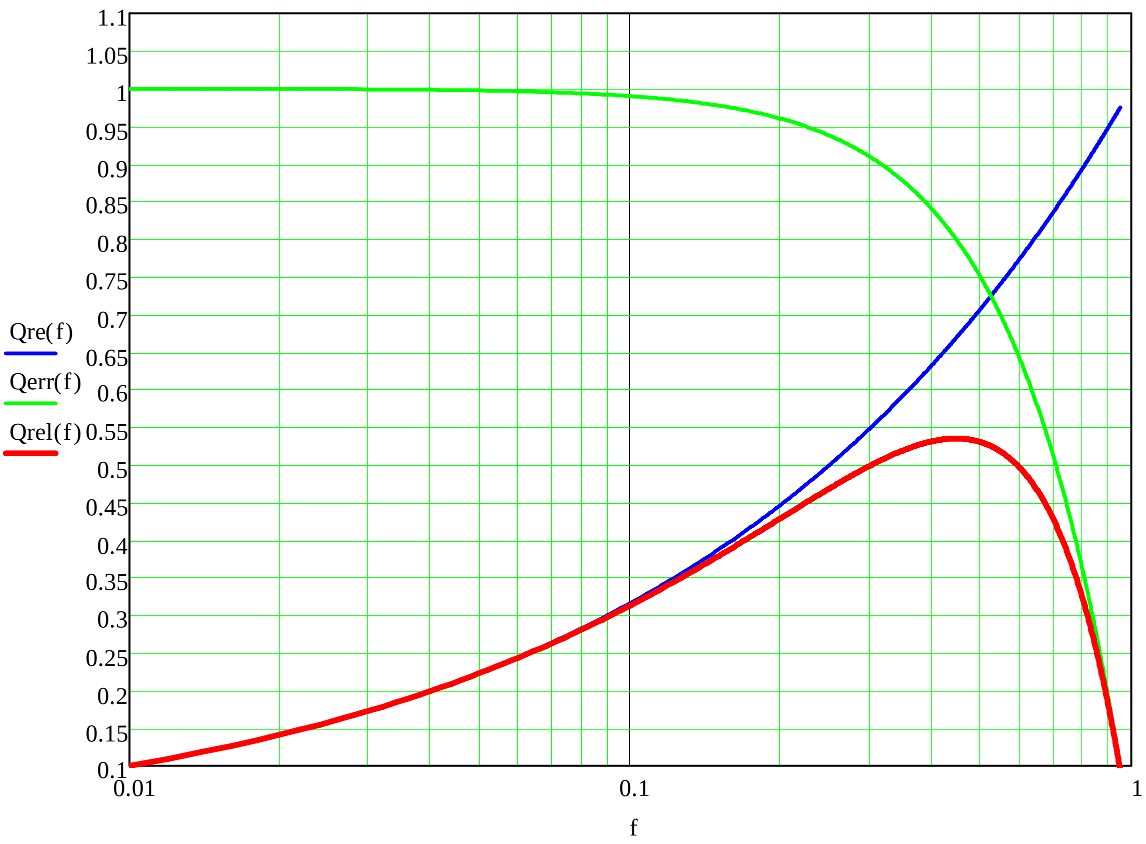
$$Lf = \frac{L}{1 - \left(\frac{f}{f0}\right)^2} \qquad Qf = Qeff\cdot\left[1 - \left(\frac{f}{f0}\right)^2\right]$$

Influence of f/f0 on Q

the Q-factor is proportional to sqrt(f). That is certainly true for frequencies far below f0.This behaviour has been allowed for by the calculations not using the corrections. As soon as we get nearer to the SRF the Q is below the calculated value. E.g. at f = 0.3 * f0 the error is 10%. In order to get the right value we have to multiply the calculated value by Qerr(f). Knowing this function allows to convert the Q to any frequency below f0.

$$f := 0.01, 0.012 .. 0.95 \qquad f0 := 1 \qquad Qre(f) := \sqrt{f} \qquad Qerr(f) := 1 - \left(\frac{f}{f0}\right)^2 \qquad Qrel(f) := \sqrt{f}\cdot\left[1 - \left(\frac{f}{f0}\right)^2\right]$$

max @ $f = 0.447\cdot f0$



convert Q from f to f2

$$Q2 = Qcorr\cdot\frac{1 - \left(\frac{f2}{f0}\right)^2}{1 - \left(\frac{f}{f0}\right)^2} = Qcorr\cdot\frac{f0^2 - f2^2}{f0^2 - f^2} \qquad Qeff = Q\cdot\left[1 + \left(\frac{f}{f0}\right)^2\right]$$